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COVID-19, the Built Environment, and Health

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Background: Since the dawn of cities, the built environment has both affected infectious disease transmission and evolved in response to infectious diseases. COVID-19 illustrates both dynamics. The pandemic presented an opportunity to implement health promotion and disease prevention strategies in numerous elements of the built environment.

Objectives: This commentary aims to identify features of the built environment that affect the risk of COVID-19 as well as to identify elements of the pandemic response with implications for the built environment (and, therefore, for long-term public health).

Discussion: Built environment risk factors for COVID-19 transmission include crowding, poverty, and racism (as they manifest in housing and neighborhood features), poor indoor air circulation, and ambient air pollution. Potential long-term implications of COVID-19 for the built environment include changes in building design, increased teleworking, reconfigured streets, changing modes of travel, provision of parks and greenspace, and population shifts out of urban centers. Although it is too early to predict with confidence which of these responses may persist, identifying and monitoring them can help health professionals, architects, urban planners, and decision makers, as well as members of the public, optimize healthy built environments during and after recovery from the pandemic. https://doi.org/10.1289/EHP8888

Introduction

Cities have always confronted outbreaks of disease—plague and cholera, yellow fever and tuberculosis. These outbreaks have influenced the built environment in countless ways. As the plague swept through 15th century Europe, Italian cities built lazarettos—pesthouses in which the afflicted could be quarantined (Figure 1). Milan's lazaretto, a crowded 33 acre (13 hectare) hellhole surrounded by high walls, was memorably described by the 19th-century Italian novelist, Alessandro Manzoni:

> . . .the lazaretto, with a population of sixteen thousand sufferers from the plague; its vast interior space crammed with huts and shacks, with carts and people; the two endless colonnades on the right and left full and overflowing with the dying and the dead, lying mingled together on straw mattresses or on bare straw; and throughout the immense compound, an agitation, a sort of undulation; and here and there, a coming and going, a pausing, a hurrying, a stooping, a rising up, of convalescents, of frantic people, of attendants. (Manzoni 1984)

In the 19th and 20th centuries, sanitary reformers in Europe and North America confronted rapid urbanization and industrialization, as well as frequent outbreaks of diarrheal diseases and tuberculosis. They championed infrastructure such as municipal water and sewer systems; building codes to assure adequate light, fresh air, and bathrooms; and zoning that separated noxious industries from residential areas, all examples of built environment strategies informed by, and targeted at, infectious diseases (Melosi 2000; Rosen 2015).

Six centuries after the first lazaretto was built, COVID-19 erupted around the world. Cities were again early targets. In the most crowded and deprived urban settings, the attack rate was terrifying: a study in Mumbai <4 months after the city's first confirmed case found a seroprevalence of 55–61% in slum neighborhoods, compared with 12–19% in non-slum neighborhoods (Malani et al. 2021). Some argued that such risk would permanently undermine the appeal of cities. Urban geographer Joel Kotkin, for instance, wrote that "a globalized world that spreads pandemics quickly will push workers back into their cars and out to the hinterlands" (Kotkin 2020). However, other commentators disagreed. ". . .[R]umors of the impending demise of the city due to fear of pandemic have been greatly exaggerated," wrote ecologists Rob McDonald and Erica Spotswood (McDonald and Spotswood 2020).

Whichever of these predictions proves to be more accurate—and only time will tell—two observations are relevant. First, throughout history, cities have rebounded from pandemics, continuing to attract people with the promise of opportunity, vibrant lives, and prosperity. Second, in the course of that rebound, as two Egyptian commentators noted, "Epidemics have transformed our built environment because of the fear of infection" (Megahed and Ghoneim 2020). "Consequently," they continued, "architecture and urbanism after the Covid-19 epidemic will never be the same." What features of the built environment played a role in the spread of COVID-19, and what lessons and practices may emerge from the pandemic (Sharifi and Khavarian-Garmsir 2020)?

Features of the Built Environment That Increase Disease Risk

Several features of the built environment increase risk of COVID-19 transmission. Chief among them are crowding [indoor far more than outdoor (Bulfone et al. 2021)], disparities due to poverty and racism, poor indoor air circulation, and ambient air pollution.

Crowding

Close proximity to other people, especially without masks and during activities such as talking, shouting, and singing, or while coughing and sneezing, emerged early as a risk factor for disease transmission (Rader et al. 2020; Rocklöv and Sjödin 2020). Crowded indoor places—prisons, churches, dormitories, buses, and workplaces such as meatpacking plants—were implicated in outbreaks (Leclerc et al. 2020; von Seidlein et al. 2021). A study in Hong Kong examined a range of built environment settings and identified two relatively crowded settings for disease transmission: restaurants and public markets (Yip et al. 2021). Similarly, a study

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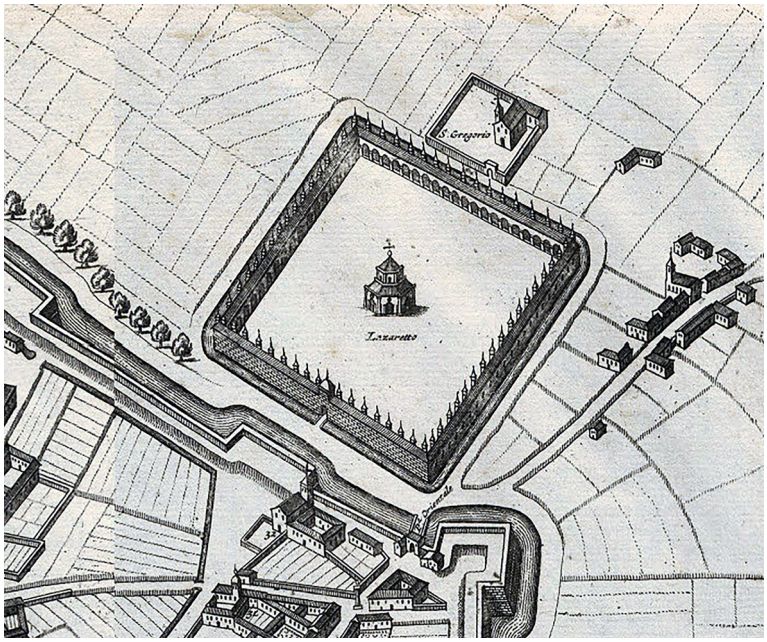

Figure 1. Milan's lazaretto, built just outside the city's walls in the late 15th and early 16th centuries to house plague victims. Having outlived its usefulness, it was demolished about 400 y later. This part of Milan, Porta Venezia, is now a vibrant neighborhood of galleries and ethnic restaurants—or it was until COVID-19 struck. Source: https://commons.wikimedia.org/wiki/Category:Lazzaretto_(Milan)#/media/File:Lazzaretto_di_Milano_1704.jpg.

in New York found that crowded home environments—a typical feature of poor neighborhoods—raised the risk of airborne disease transmission in pregnant women (Emeruwa et al. 2020). In some studies, crowded neighborhoods had higher transmission rates than less crowded neighborhoods (Kadi and Khelfaoui 2020; Zhang and Schwartz 2020)—a pressing challenge in such cities as Mumbai, Nairobi, and Karachi, where substantial portions of the city consist of slums. Restrictions on the level of occupancy of stores, eating and drinking establishments, theaters, sporting events, and places of worship quickly emerged (Figure 2).

Some observers, such as New York Governor Andrew Cuomo, equated crowding with urban density and decried the risks of density (Toderian 2020). Indeed, some research linked urban density to disease transmission, especially in the first months of the pandemic (Cartenì et al. 2020; Gerritse 2020; Kulu and Dorey 2021; Whittle and Diaz-Artiles 2020; Wong and Li 2020). However, crowding is not the same as density. As urban planner Brent Toderian pointed out, "Density is generally used as a measure of how many people live and work on how much land, or how much building space is in an area. Crowding is literally how close everyone is to each other at a given time and place. You can have density without crowding, and you can have crowding without density" (Toderian 2020). Studies found that although large cities initially had higher rates of COVID than other places, density did not independently predict infection incidence, perhaps because city residents were more able or willing to socially distance, wear masks, and otherwise take protective actions (Boterman 2020; Carozzi et al. 2020; Hamidi et al. 2020; Hamidi and Zandiatashbar 2021; Teller 2021), or because cities had more effective governance and public health infrastructure (Connolly et al. 2021), or both. An analysis of global cities found that the timeliness of control measures was a stronger predictor of disease rates than was density (Bai et al. 2020), underlining the importance of behavioral precautions in stopping transmission. Residents of compact neighborhoods were found to have reduced their shopping trips more than did residents of suburban and rural areas—perhaps because of a greater ability to trip-stack, greater availability of delivery services, greater willingness to observe stay-at-home guidelines, or some combination of these (Hamidi and Zandiatashbar 2021). Consistent with this hypothesis, an analysis of New York City neighborhoods found that exposure density—a measure of activity outside the home—was a stronger predictor of COVID-19 incidence than was population density (Hong et al. 2021). In some cases, dense neighborhoods may be protective, manifesting a form of resilience. "Barring supply chain collapse," wrote Ben Holland of the Rocky Mountain Institute, "they far outperform suburban communities in their access to food and other critical needs during crises. . ." (Holland 2020a).

Although crowded places can be a risk factor for COVID, evidence suggests that density is not destiny. Dense cities with capacious sidewalks, parks, and public spaces provide enough space to enable people to avoid crowding. Social and behavioral factors play decisive roles as well, sometimes eclipsing the effects of density. If history is any indication, people will always want to gather. It is likely that future designers of buildings and communities, mindful that disease outbreaks will recur, will need to incorporate ways of reducing close person-to-person contacts when needed and will need to facilitate behavioral changes that reduce risk.

Poverty and Racism

Poverty and racism are generally viewed more as social than as environmental factors. But both poor people and people of minority racial and ethnic backgrounds concentrate in certain neighborhoods, and these neighborhoods often suffer from poor health—hence the frequent observation that "your Zip code determines your health more than your genetic code" (Diez Roux and Mair 2010; NASEM 2017; Williams and Collins 2001). Throughout the COVID-19 pandemic, the risk of infection, and the risk of dying, were differentially distributed across neighborhoods within cities, with both poverty and racial/ethnic minority status key predictors of risk. In a study of 158 counties in 10 U.S. metropolitan areas with early COVID-19 surges, the higher the proportion of the non-White population, the higher the incidence and mortality from COVID-19—a gradient that was steeper in poorer

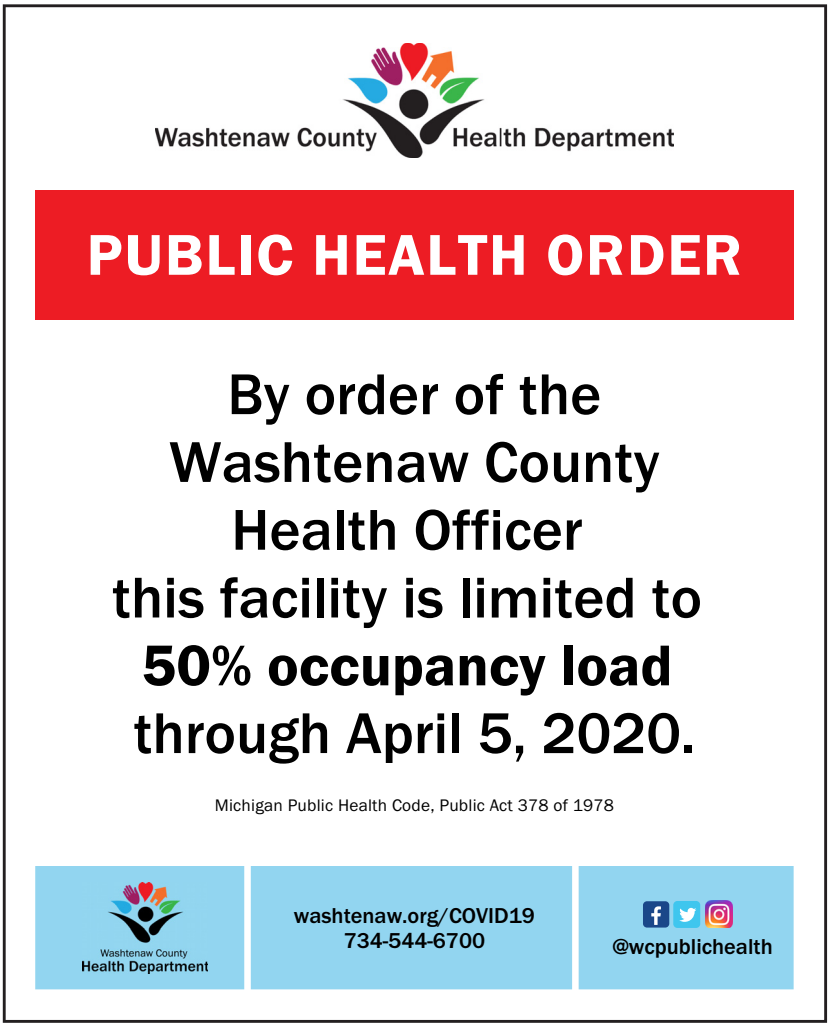

Figure 2. As accumulating evidence showed that SARS CoV-2, the cause of COVID-19, spread by airborne transmission, many jurisdictions limited the number of people who could be in indoor spaces. Source: Washtenaw County (Michigan) Health Department, used with permission.

counties (Adhikari et al. 2020). A census tract-level study in Louisiana found that people in the most deprived neighborhoods had a nearly 40% higher risk of contracting COVID-19 than those in the least deprived neighborhoods (KC et al. 2020). Similar results emerged in studies in numerous locations (Andersen et al. 2021; Bilal et al. 2021; Das et al. 2021; De Ridder et al. 2021; Emeruwa et al. 2020; Hu et al. 2021a; Lewis et al. 2020; Nguyen et al. 2020; Scannell Bryan et al. 2021).

What accounts for this geographic variation? Worse baseline health, worse health care access, and fewer available intensive care unit beds in high-risk neighborhoods all likely contributed (Arasteh 2020). More crowded housing, precluding people from distancing from each other, likely played a role (Baidal et al.2020). Health-promoting assets such as parks and greenspace are in short supply in low-income and minority communities (Nesbitt et al. 2019; Schüle et al. 2019). Importantly, high-risk neighborhoods were more likely to be home to frontline workers—delivery workers, grocery store clerks, nursing home aides, and others whose jobs entail contact with the public (Cox-Ganser and Henneberger 2021), who were unable to work from home, and who often had to commute by public transit (Do and Frank 2021). The defining characteristics of COVID-19 hot spot neighborhoods varied from city to city; in New York City, the concentration of frontline workers was the strongest predictor of disease incidence, whereas in Chicago, the levels of poverty and unemployment and the proportion of Black residents were more predictive (Maroko et al. 2020). But the general pattern of COVID-19 risk varying by neighborhood, reflecting "upstream" social determinants of health, was a stark reminder of persistent inequities in the built environment, requiring wide-ranging political, economic, and social solutions (Johnson-Agbakwu et al. 2020; Naik et al. 2019).

Poor Air Circulation

If the air in an indoor space is poorly circulated, especially if the space is crowded and if people do not use masks, then the risk of exposure to airborne aerosols increases (Bhagat et al. 2020; Nishiura et al. 2020; Schoen 2020). Accordingly, recommendations from researchers, professional societies, and governments worldwide included increasing the supply of outdoor air, limiting air recirculation, increasing air filtration, maintaining exhaust ventilation in areas such as kitchens, and using ultraviolet germicidal irradiation in some circumstances (Burridge et al. 2021; CDC 2020; Guo et al. 2021; Morawska et al. 2020). Although some measures, such as opening windows and using fans, cost little or nothing, major improvements to heating, ventilation, and air-conditioning (HVAC) systems can be costly to install and operate. Moreover, current HVAC systems are designed to manage temperature, humidity, and contaminant levels under nonpandemic conditions; modifying them to deliver very large volumes of clean air could be inefficient, energy consuming, and costly. As a result,

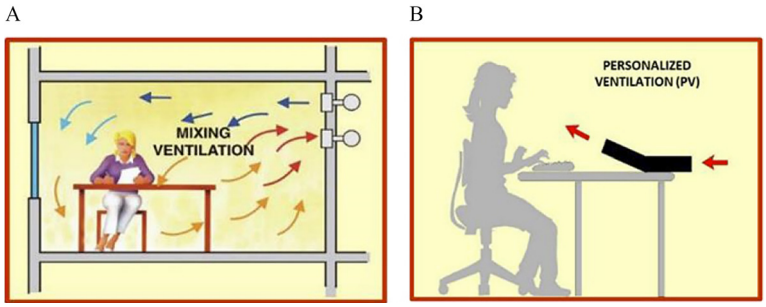

Figure 3. (A) Conventional ventilation vs. (B) personalized ventilation. Ventilating an entire room requires more energy, is costlier, and may offer less protection from infection than delivering fresh air directly to people's breathing zones. Reprinted from Building and Environment, 186, Arsen K. Melikov, COVID-19: Reduction of airborne transmission needs paradigm shift in ventilation, 107336. Copyright (2020), with permission from Elsevier.

some have suggested that new HVAC paradigms are needed. These will need to balance thermal comfort, fresh air exchanges, and reducing energy use (Allen and Ibrahim 2021; Burridge et al. 2021; Ferdyn-Grygierek et al. 2019). Two examples of such an approach are supplying personal ventilation directly to people's individual breathing zones (say, at their workstations; Figure 3B) instead of ventilating the entire interior building space (Figure 3A) (Melikov 2020) and using precision HVAC based on localized monitoring and artificial intelligence guidance (Ding et al. 2020).

Air Pollution

A fourth aspect of the built environment that can increase risk is poor air quality. Within months of the initial outbreak of COVID-19, evidence emerged linking higher ambient levels of fine particulate matter and oxides of nitrogen with increased risk of COVID incidence, severity, and mortality. Within cities, neighborhoods near such sources as roadways and waste facilities—where residents are disproportionately poor and members of minority groups—were at particular risk, helping to explain part of the excess risk of COVID-19 seen in these populations (Ali and Islam 2020; Copat et al. 2020; Hendryx and Luo 2020; Hernández-Paniagua et al. 2021; Karan et al. 2020; Kumari and Toshniwal 2020; Li et al. 2020; Liang et al. 2020; Naqvi et al. 2021; Travaglio et al. 2021; Woodby et al. 2021; Wu et al. 2020; Zhu et al. 2020). [This evidence consists largely of ecological studies, which carry some risk of bias (Villeneuve and Goldberg 2020).] Conversely, the economic slowdown triggered by the pandemic, with drastic reductions in traffic and other pollution sources, delivered some of the cleanest urban air in memory (Gautam et al. 2021; Hernández-Paniagua et al. 2021; Kanniah et al. 2020; Roy and Singha 2021; Shi and Brasseur 2020; Vadrevu et al. 2020; Venter et al. 2020a). Unaccustomed clean air may have inspired people long inured to poor air quality, raising expectations for the post-pandemic recovery. Although there were already many reasons to reduce ambient air pollution, reducing the risk of COVID-19 reinforced this health and environmental mandate.

Potential Long-Term Implications of COVID-19 for the Built Environment

The pandemic led to a wide range of adaptive changes in the built environment, from the scale of buildings to the scale of entire cities. Although the pandemic was tragic and destructive, some of the responses had great appeal, and they could be promising models for long-term use: repurposing streets for pedestrians and cyclists, reinforcing the use of parks, and improved urban air quality through reduced driving. Other changes, such as relocation to exurban locations, are more complex and nuanced, and their long-term implications are unclear.

Infection-Safe Buildings?

As discussed above, changes in building HVAC systems can help provide clean air and reduce the risk of infection. But this is not the only building design strategy that could emerge as a long-term legacy of the COVID-19 pandemic. Providing building features that permit physical distancing can help reduce airborne transmission of microbes and may offer additional health and well-being benefits. One example is wider hallways and staircases; even in nonpandemic times, more attractive stairways can encourage the use of stairs, which promotes physical activity. Similarly, design elements such as personal balconies and shared courtyards allow people to get outside and to socialize while maintaining distance; these can provide nature contact, and exemplify "density done right" that is appealing and functional even when there is no pandemic (Roberts 2020). Courtyards can vary greatly in the extent of air circulation they provide, depending on size and geometry; design strategies that maximize air movement in courtyards may become more popular following the pandemic (Leng et al. 2020).

Working from Home instead of at the Office?

COVID-19 brought a large-scale shift to working from home, for those whose jobs permitted it. Will this persist? One view holds that the physical workplace will rebound—that employers will prefer in-person operations and that employees will be drawn back to the workplace by social interaction, a professional working environment, and the chance to separate home life from work life (Figure 4) (Florida et al. 2020). This could entail reimagining the role of the office. According to one scenario, future offices might have fewer people in them, with people working from home 1 or 2 d per week, but with the office remaining central to work life, perhaps maximizing its appeal and value by offering amenities such as more space per person, learning and development opportunities, entertainment, food, and fitness facilities (Ulbrich 2020).

Alternatively, teleworking may persist. Companies may emerge from the COVID pandemic realizing that their employees are highly productive when working from home and that they can save money by downsizing their offices. Moreover, as one commentator opined, "people do not really want to get back to the office. . .The commute will still be long; there will still be too many meetings and time-sucks; it will still feel like a mad rush to get out the door in the morning or get dinner on the table at night" (Petersen 2020). There is evidence that many employees would embrace working from home. In a Pew Research Center survey in October 2020 among employees who said that their job responsibilities could be carried out at home, 54% said they would want to work from home after the COVID-19 pandemic had ended (Parker et al. 2020). Another survey by the consulting firm PwC, in early June 2020, found that 83% of

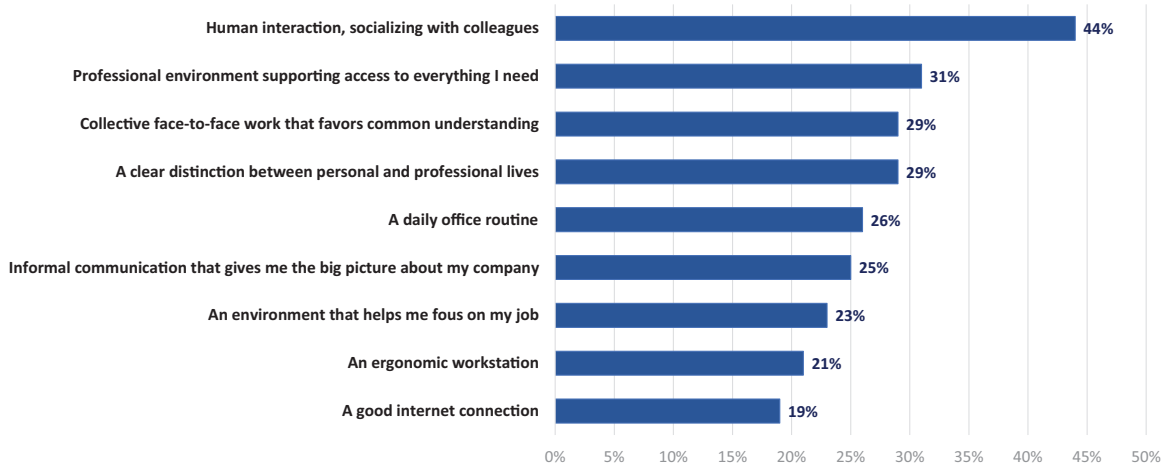

Figure 4. What employees miss most about being in the office. Results of a May 2020 survey of 3,000 respondents across North America, Europe, and Asia. Source: (Ulbrich 2020); data from JLL, used with permission.

workers wanted to continue working from home at least 1 d a week after the pandemic, including 32% who wanted to do so full time (PwC 2020).

As the pandemic evolved, major employers such as Facebook, Google and Twitter announced plans for large-scale, long-term shifts toward teleworking (Conger 2020; Dwoskin 2020; Wakabayashi 2020). A year into the pandemic, the *Financial News* reported that two major London-based banks, HSBC and Lloyds, were embracing remote work and cutting their global office space by 40% and 20%, respectively; that the French bank Societe Generale would allow its UK employees to spend up to 90% of their work time remotely; and that more than half of JPMorgan bank traders expected to work from home at least 4 d a week (Kelley 2021). This was not just a technology and financial sector phenomenon; traditional heartland firms also embraced teleworking. Nationwide Insurance substantially downsized major office hubs in central Ohio, Des Moines, Scottsdale, and San Antonio and permanently closed offices in Gainesville, Raleigh, Richmond, and elsewhere (Smith 2020). As William Fulton, director of Rice University's Kinder Institute for Urban Research, wrote, "Office workers do not have to go to the office every day—and maybe not at all. They can work from home or a coffee shop just as effectively. In the wake of COVID-19, more people will work from home more often. In the long run, companies will need less office space. . ." (Fulton 2020).

The future of teleworking is likely to vary by location, economic sector, and earning level; higher-paid workers have more flexibility to work from home than those lower on the economic ladder (Parker et al. 2020). Estimates suggest that about one in three U.S. workers, but only about one in eight workers in low-income countries, can work from home (Dingel and Neiman 2020; ILO 2020; Saltiel 2020).

Long-term growth in teleworking could have far-reaching consequences. Reduced commuting could reduce energy use and air pollution in metropolitan areas, although some of the energy savings are countered by increased home energy use and non-work travel (Hook et al. 2020). If more teleworking reduces the daytime population in city business districts, that could squeeze the businesses that serve office workers, from restaurants to bookstores to fitness clubs. A shift from office-based work to home-based work could drive demand for larger homes that include office space.

Working from home (WFH) has occupational health implications (Tavares 2017). One category of risk is ergonomic, due to unsuitable home workstations. Early in the pandemic, media accounts described widespread complaints of musculoskeletal strain and symptoms when people switched from ergonomic office furniture to long hours on laptops on their sofas, beds, and kitchen counters (Wilser 2020). Some (Moretti et al. 2020) but not all (Aegerter et al. 2021) studies corroborated this finding. Another category of WFH-associated risk is psychosocial, due to blurred boundaries between work and home, concurrent home responsibilities (such as childcare), increased workload, and social isolation (Bouziri et al. 2020; Ingusci et al. 2021). These impacts may disproportionately affect women (Arntz et al. 2020). Evidence during the pandemic showed heterogeneous responses to WFH—decreased stress in some workers, increased stress in others (Aetna International 2020; Moretti et al. 2020; Tušl et al. 2021; Weitzer et al. 2021). A third health impact of WFH reported during the pandemic was weight gain (Aetna International 2020; Ekpanyaskul and Padungtod 2021); while this may relate to the general decrease in physical activity during the shutdown, it may also reflect the decline in commuting-associated physical activity (Abolanle et al. 2020; Raza et al. 2020). Other occupational health concerns of WFH include poor lighting, noise, and injury risks. Both Occupational Safety and Health Act regulations and Workers Compensation provisions generally apply to WFH (OSHA 2000; Wise 2021), so employers must, to a reasonably practicable extent, ensure safe and healthy working conditions for WFH employees.

Reenvisioned Streets?

As COVID-19 exploded during the first half of 2020, travel demand plummeted, and traffic on city streets fell precipitously. Meanwhile, people confined to their homes yearned to get outdoors for relief, seeking fresh air and physical activity. Conventional sidewalks became crowded and were too narrow to permit people to maintain the recommended distance from each other. In response, many cities closed streets to traffic and designated them for pedestrians and cyclists. Bogotá's Ciclovía, a 120-km (75-mi) street network dedicated to cycling 1 d each week, expanded to 7 d per week, and Oakland, California, restricted vehicle access on 120 km (75 mi) of its streets, or about 10% of its street network (Schwedhelm et al. 2020). Other cities, from Boston to Seattle to San Antonio, from Athens to Lima to Sydney, took similar steps—some intended to be permanent (Combs and Pardo 2021; NACTO 2020). Milan announced its *Strade Aperte* (Open Streets) plan in April 2020, including cycle lanes, new and widened pavements, reduced speed limits, pedestrian and cyclist priority streets, and, with delightful poetic justice, a low-traffic

Figure 5. Mainkai Street, Frankfurt, during the COVID-19 pandemic in 2020. Once the street was closed to vehicles, pedestrian and bicycle activity substantially increased. Source: Photography by Beatriz Kauark, from Pandit et al. (2020). Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/).

neighborhood on the very site of the city's former lazzaretto (Laker 2020). These alterations aimed not only to facilitate walking and cycling, but also to create spaces for outdoor dining, markets, and even school classes; to make room for people to queue up when entry to stores was limited; and to permit delivery vehicles to operate (NACTO 2020).

City officials reported increased pedestrian use of the streets. In Oakland, one observer wrote, "As if in an earlier era, small children are riding bikes in the middle of the street without their parents needing to worry" (Bliss 2020). In Frankfurt, when an 800-m stretch of the Mainkai riverfront was closed to vehicles, both utilitarian and recreational physical activity rose dramatically: by 45% in peak-hour cycling, 20% in peak-hour walking, 1,150% in children cycling independently, and 25% in the presence of people with restricted mobility (Figure 5) (Pandit et al. 2020). It remains to be seen how much such street reallocations catch on with the public, planners, and city officials, and how many of the changes outlast the COVID-19 pandemic.

Changing Modes of Travel?

The COVID-19 pandemic brought a dramatic reduction in the use of mass transit as people both reduced their travel and shifted to other modes, afraid of getting infected on crowded buses, subways, and rail cars (Abdullah et al. 2020; Ahangari et al. 2020; Aloi et al. 2020; Jenelius and Cebecauer 2020) (Figure 6). In some systems, ridership fell by more than 90% (Aloi et al. 2020; Liu et al. 2020; Olin 2020). Initially, some cities began running buses and trains at higher frequency while restricting the number of passengers on board (Kamga and Eickemeyer 2021). Some cities made transit riding free. Both approaches could boost transit use in the long run given that higher frequency transit greatly increases convenience and low prices incentivize transit use. Transit use promotes health by increasing physical activity (Rissel et al. 2012; Xiao et al. 2019).

However, because low ridership devastated their revenues, transit systems came under intense financial pressure. Budget

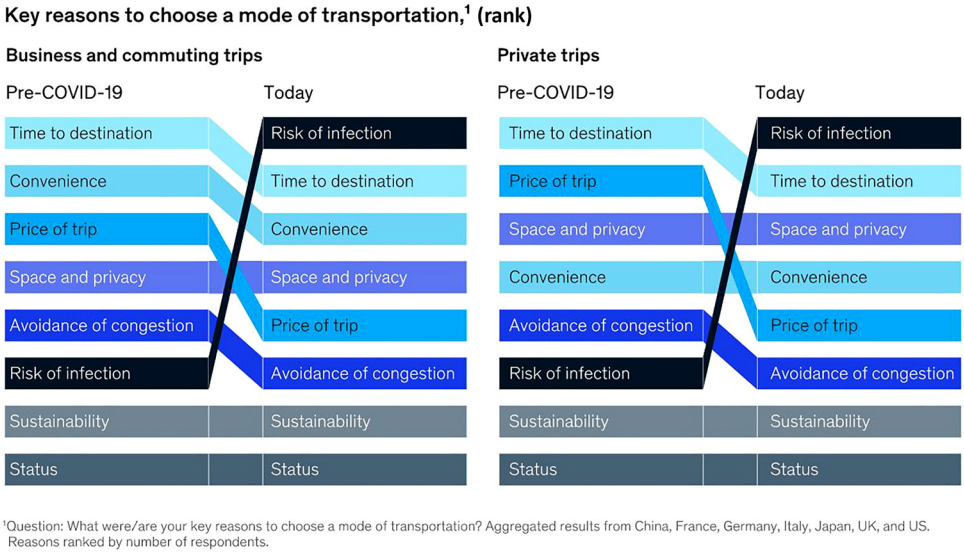

Figure 6. People's reasons for preferring one or another mode of transportation shifted during the COVID-19 pandemic, with risk of infection overtaking usual reasons such as time and convenience. This shift led to a dramatic decline in the use of mass transit. Exhibit from "Five COVID-19 aftershocks reshaping mobility's future," September 2020, McKinsey & Company, http://www.mckinsey.com. Copyright (c) 2021 McKinsey & Company. All rights reserved. Reprinted by permission.

shortfalls across U.S. transit systems collectively ran to the tens of billions of dollars (EBP 2021). By several months into the pandemic, many transit systems were slashing their services and laying off staff. Reductions in service forfeit many of the health and social benefits of transit. Moreover, they disproportionately impact poor people and people of color, who account for a large share of transit riders in many cities (Clark 2017). A prolonged contraction of urban mass transit could be catastrophic. As one commentator wrote,

> Without reliable public transit, a modern city simply cannot function properly. Students can't get to school, the majority of employees who can't do their job from home can't get to work, and retailers in central business districts are left hawking their merchandise along empty streets. (Thompson 2020)

Fortunately, studies suggest that COVID-19 transmission on buses, subways, and trains during the pandemic was relatively rare. Monitoring in cities such as Paris, Tokyo, and Milan attributed few if any outbreaks to transit use (1% of clusters in Paris, none in Tokyo or Milan), likely because riders were compliant with mask wearing (Joselow 2020). Taipei and Hong Kong, where transit ridership remained relatively high throughout the pandemic, did not suffer outbreaks related to transit use (Joselow 2020; Sadik-Khan and Solomonow 2020). An analysis in New York City showed no association between subway ridership and COVID-19 infection rates (Hamidi and Hamidi 2021). Modeling of Singapore's busy bus system (3.9 million riders daily in a population of 5.7 million) showed that certain interventions—especially universal mask-wearing and isolation of super-spreaders identified through the use of smart cards—could greatly limit disease transmission (Mo et al. 2021). However, the use of transit relates as much to public confidence as to objective data.

As travel recovered after the first wave of COVID-19, automobile traffic increased far faster than did transit ridership, in cities from São Paulo to Seattle to Sydney (Bliss et al. 2020; Polzin and Choi 2021). The pronounced shift from transit to private automobiles (Olin 2020), if persistent, could intensify traffic congestion in many cities (Hu et al. 2020) and increase the associated health risks, including reduced physical activity, air pollution, noise, motor vehicle injuries, and stress (Nieuwenhuijsen and Khries 2018).

Rideshare services such as Uber and Lyft also saw dramatic reductions in use during the pandemic because people worried about being in close quarters with strangers. In May 2020, media accounts reported that Uber's ride-sharing business had declined by 80% compared with a year earlier (Hawkins 2020).

In contrast, bicycling emerged as a preferred mode of travel. Excluding periods of lockdown, year-on-year cycling increased 67% in Paris, 43% in Barcelona, and 17% in New York City—a trend that was likely encouraged by many cities' expansion of cycling infrastructure (Buehler and Pucher 2021; Kraus and Koch 2021). Survey data from Thessaloniki, Greece (Nikiforiadis et al. 2020), and Sydney, Australia (Lock 2020), indicated increased public willingness to rely on cycling, and survey data from the United States revealed increased intention to bicycle following the pandemic (Ehsani et al. 2021). Bicycle sales in 2020, compared with 2019, rose 39% in the United States, 20% in Italy, 27% in France, 20% in the UK, 17% in Germany, and 23% in Australia (Buehler and Pucher 2021) even as media reports described severe supply shortages (Annis 2020; Goldbaum 2020; Zhong 2020). These observations may portend long-term increases in cycling.

Bikeshare programs proved to be relatively resilient (although evaluation of year-on-year bikeshare trends is complex because the pandemic featured lockdown orders, price reductions, incentive programs, and other factors that could have influenced use). In some cities, such as Boston (Tokey 2020), Chicago (Hu et al. 2021b), New York City (Hu 2020; Pase et al. 2020), Budapest (Bucsky 2020), and Seoul (Park et al. 2020), bikeshare use surged in the early weeks of the pandemic relative to the same calendar weeks a year earlier, while in other cities, bikeshare use declined with the onset of the pandemic (Tokey 2020). In most cities, bikeshare use fell as lockdowns were imposed but recovered relatively rapidly as the pandemic progressed, far more rapidly than did transit use (Pase et al. 2020; Tokey 2020). Bikeshare network expansions, such as free membership for essential workers, may have inadvertently discriminated against members of minority groups, because of disproportionate placement of docking stations, eligibility requirements, and other factors (Nguemeni Tiako and Stokes 2021). By late 2020, bikeshare use had rebounded and was setting records in New York City and London, according to an analysis of use data by the *City Monitor* (Kanik 2020).

The future of travel after the pandemic is unclear. If transit systems confront residual financial pressure, there could be a transit death spiral of reduced service, deferred maintenance, and staffing shortfalls, leading to decreased ridership. If, on the other hand, transit systems rebound (which will require significant government investment), then transit ridership may well return to prepandemic levels. Shifts to walking and cycling during the pandemic may have staying power, especially in cities that make long-term improvements to infrastructure, such as dedicated streets, suggesting that the pandemic could propel the adoption of healthy, sustainable travel modes (King and Krizek 2020; Schmidt et al. 2021).

A New Appreciation for Greenspace and Nature?

Around the world, as national, state, and local governments sought to limit the spread of COVID-19, they imposed lockdowns or issued stay-at-home orders. Cabin fever struck. People became restless and lonely, anxious, and depressed (Brooks et al. 2020). In response, many people sought respite in natural settings such as parks—not a surprise, given the well-established restorative qualities of nature contact (Kleinschroth and Kowarik 2020; Slater et al. 2020).

However, in many places, parks were closed (Figure 7). In some cases, park closures were part of more sweeping restrictions. In other cases, parks initially remained open, but authorities found that visitors were congregating in large numbers without physical distancing and responded by restricting entry. Considerable public pushback to park closures arose in many places. Some experts, having considered the balance of risks and benefits, advocated the judicious opening of parks (Freeman and Eykelbosh 2020; Razani et al. 2020; Slater et al. 2020). In some jurisdictions, park restrictions were among the first to be relaxed (Day 2020). In Barcelona, officials compensated for unpopular strict park restrictions by allowing people out to work in vegetable gardens (Barton et al. 2020).

Meanwhile, evidence of heightened demand for nature contact emerged. In Barcelona, people increased the time spent on green roofs (Barton et al. 2020). In cities across the United States, mobile phone tracking revealed that even as shopping trips fell pursuant to stay-at-home orders, urban park visits continued undiminished (Hamidi and Zandiatashbar 2021). There were dramatic year-on-year increases in the issuance of hunting and fishing licenses across the United States (Brown 2020). Park visits rose in Stockholm (where parks remained open) (Barton et al. 2020) and England (as soon as park restrictions were relaxed) (Day 2020). In Hong Kong, people flocked to the scenic Tai Po reservoir at weekend levels throughout the week (Tsang 2020); in a survey of Hong Kong park visitors, 78.8% endorsed the statement that the park environment "helps to improve mental health by relieving my stress and anxiety brought about by the COVID-19 pandemic" (Ma et al. 2021).

Figure 7. Parks, beaches, and other outdoor destinations closed to minimize the spread of COVID-19, reducing access to an established means of health promotion (Kondo et al. 2018; Reyes-Riveros et al. 2021). Photo reused from Wikimedia commons: https://bit.ly/35KRm0G and licensed under the Creative Commons Attribution–Share Alike 4.0 International license: https://creativecommons.org/licenses/by-sa/4.0/legalcode.

When urban parks were closed, people in Italy increased their visits to nearby small urban gardens, people in Spain and Israel increased their strolling on tree-lined streets, and people in Lithuania and Croatia drove more than usual to green areas outside the city (Ugolini et al. 2020). A detailed study in Oslo, using STRAVA data, Google mobility data, and pedestrian and bicycle counts, revealed a 291% year-on-year increase in outdoor activity, which was greatest on the greenest, least urbanized trails (Venter et al. 2020b). In numerous countries, Internet searches on such terms as "outside" and "garden" increased (Figure 8).

There is an important equity dimension to parks and greenspace. Access to these amenities is unequally distributed, with poor and minority communities relatively deprived (Jennings et al. 2017; Nesbitt et al. 2018, 2019). Some evidence suggested that this racially disparate nature deprivation was associated with reduced well-being during the pandemic (Tomasso et al. 2021). Conversely, the presence of greenspace may have had a salutary effect on racial disparities in COVID-19 infections. An ecological study of 135 urbanized U.S. counties found that more county-level greenspace was associated with lower racial disparities in infection (Lu et al. 2021). This finding aligns with earlier evidence of an equigenic impact of greenspace (Mitchell and Popham 2008; Rigolon et al. 2021) and supports the value of greenspace as a strategy for health equity in the pandemic recovery (Geary et al. 2021; Mell and Whitten 2021).

One lasting legacy of COVID-19 could be a fear of using public spaces such as parks (Payne 2020). However, nature contact clearly emerged as a highly valued amenity during the pandemic. Accordingly, the pandemic's long-lasting impact may include the creation of more parks in urban areas, changes in park design such as wider paths to permit physical distancing, and better maintenance of existing parks (Honey-Rosés et al. 2020; Lennon 2020; Nobajas et al. 2020). Funds for this purpose may be available through government infrastructure investment as part of the post-COVID recovery.

A Shift from Cities to Exurbs and Rural Areas?

History is replete with accounts of people of means fleeing cities to escape outbreaks of disease, from the colonial British hill stations in India (Kennedy 1996) to the many fugitives from Philadelphia to the Pennsylvania countryside during the 1793 yellow fever outbreak (Powell 1949). During the COVID-19 pandemic, in at least some cities, people fled as well. In mid-March, 2 wk after the first case of COVID-19 was confirmed in New York City, the *New York Times* reported a "panicked exodus" of wealthy New Yorkers to their second homes (Bellafante 2020). By 1 May 2020, 6 wk later, mobile phone tracking data revealed that hundreds of thousands of New Yorkers had departed, presumably to second homes, vacation rentals, or sojourns with friends or family. This trend was especially marked in wealthier neighborhoods; one analysis estimated that up to 20% of people in New York City's wealthiest neighborhoods had departed the city (Coven et al. 2020), and a tabulation by the *New York Times*, using data from the geospatial analysis firm Descartes Labs, estimated a proportion twice that high (Quealy 2020). Over one million residents of greater Paris decamped when COVID-19 restrictions were imposed in March 2020 (Weisbuch 2021).

However, COVID-19 differed from historic waves of infectious disease. Those who left the city could work remotely thanks to the Internet. They could shop using on-line retailers. They could access health care using telemedicine. They could remain in touch with loved ones, and their children could attend school using Zoom—or they could attend local schools. Could the shift from cities to exurban and rural areas portend a long-term post-pandemic trend?

Some evidence suggested an underlying inclination to depart large cities. A Gallup poll in 2018 asked Americans about where they would like to live, and where they actually lived. Forty percent lived in cities, but only 29% chose a city as their preferred setting. Thirty-one percent lived in a town or a rural area, but 39% said they preferred such a setting (Newport 2018). In surveys by real estate companies several months into the pandemic, half to two-thirds of urban residents indicated that they would move out of the city if they could continue to telework (Ellis 2020; Zillow 2020). A nationwide analysis of household moves by the Federal Reserve Bank of Cleveland found that out-migration from urban neighborhoods increased by about 4% during 2020 and that in-migration fell by about 8%, resulting in net out-migration (Whitaker 2020). However, Zillow's *Urban–Suburban Market Report*, issued in August 2020, 6 months into the pandemic, found that suburban housing prices were rising no faster than urban prices (Zillow Research 2020), and Apartment List, a national real estate rental firm, reported that apartment searches in most American cities actually increased as the pandemic advanced (Salviati and Warnock 2020), suggesting no widespread migration from cities to suburbs.

How might the contours of cities change if working from home and/or urban out-migration continued? Economist Andrii Parhomenko and his colleagues (Delventhal et al. 2020; Delventhal and Parkhomenko 2020) modeled the impact on U.S. cities of large-scale post-pandemic teleworking. They predicted that many people would remain in cities, attracted by amenities such as restaurants and the arts, but that many others

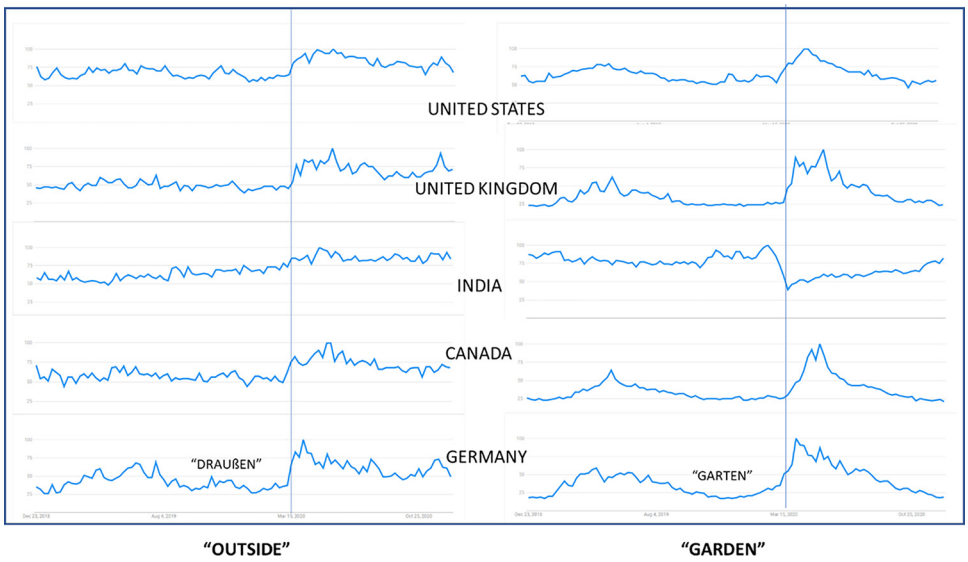

Figure 8. Google searches on "outside" (left) and "garden" (right) in four English-speaking countries and Germany, December 2018–December 2020. Note the increase in March 2020 (the vertical line marks March 15), around when COVID-19 restrictions began. (The sharp downturn in India on "garden" searches may be related to the country's southern hemisphere location.) Data source: Google Trends (https://www.google.com/trends).

would relocate toward the suburbs and beyond, freed from the need to live near work and attracted by lower housing prices and lifestyle options. On balance, there would be a redistribution away from the urban core toward the periphery. This shift could have far-reaching consequences. Large cities would shrink, and smaller cities would grow. Housing prices in large cities would fall, enabling more diverse urban populations. Businesses might distribute smaller satellite offices around a city or region in lieu of a single large headquarters. Traffic congestion would drop, and commutes would ease. Some commercial real estate in cities, vacated by businesses, might be converted to residential space, easing current housing shortages—as proposed by the Real Estate Board of New York (Haag and Rubinstein 2020).

Some commentators argued that cities would rebound after the pandemic. "Cities have been the epicenters of infectious disease since the time of Gilgamesh," wrote urbanist Richard Florida, "and they have always bounced back—often stronger than before" (Florida et al. 2020). *New York Times* columnist Farhad Manjoo pointed out that COVID-19 had in no way diminished the rationale for cities, that they are ". . .indispensable as engines of economic growth, catalysts of technological and cultural innovation. . .and. . .one of the most environmentally sustainable ways we know of for housing lots of people." In fact, Manjoo continued, "Not only are cities worth saving, they are also ripe for rebirth" (Manjoo 2020).

Conclusion

Indeed, the COVID-19 pandemic unleashed a flood of aspirational proposals for the built environment renaissance to which Manjoo referred—for "built back better" post-pandemic buildings, neighborhoods, and cities (Bloomberg City Lab 2020; Florida et al. 2020; Holland 2020b). Architects called for innovative HVAC systems and other building design features to reduce disease transmission (Megahed and Ghoneim 2020), and for designing homes with swing space to accommodate both living and working (Keenan 2020). Conservationists called for more urban parks and greenspace and for nature-based solutions (Allen 2020). Transportation planners called for rethinking streets, trading autocentrism for the "complete streets" that had proven their value during the pandemic (NACTO 2020). Clean air advocates strategized about extending some of the pandemic-related changes in polluting activities to prolong the air quality benefits (De Vito et al. 2020).

Social justice advocates called for correcting historical injustices in the built environment that contributed to health inequities. Maimunah Mohd Sharif, Executive Director of the United Nations Human Settlements Program, noted that the pandemic had exacerbated the urban divide, which reflected "long-term failure to address fundamental inequalities and guarantee basic human rights." "The post-COVID-19 response," he wrote, "will require these failures to be addressed and all urban residents provided with basic services—especially health care and housing—to ensure everyone can live with dignity and be prepared for the next global crisis" (Florida et al. 2020).

Technology enthusiasts point to the enormous potential for innovative technologies and data to improve health, service delivery, commerce, and social connectedness in cities (Acuto 2020). Disaster planners noted the need to build resilience, not only to future pandemics but to a range of disasters (Keenan 2020). They cited some surprising lessons from COVID-19. For example, following a disaster that confined people to home and brought a tragic increase in domestic violence (Moreira and Pinto da Costa 2020), will future building standards require locks on interior doors? Will homes include more capacity to stockpile food and supplies, and/or to deliver diagnostic and treatment services, such as cardiac monitoring? Neal Gorenflo, an advocate of "shareable cities," argued that post-COVID cities should become more self-governing (more independent of state and national governments), more self-sufficient financially and materially, more democratic (with residents more engaged in urban governance), and better at cooperating and sharing resources with each other (Gorenflo 2020).

Overall, the pandemic recovery offers a panoply of lessons, which will continue to emerge for years (Capolongo et al. 2020; Milner et al. 2021; Rojas-Rueda and Morales-Zamora 2021). It also offers an historic opportunity—to ground placemaking firmly in human needs, justice, and environmental sustainability; to adopt indicators and metrics that reflect those priorities; to improve the efficiency and fairness of urban governance; and to harness emerging technology to make healthier, more sustainable, and more resilient places than ever before (Tompkins 2020).

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